ARL-FLIGHT-MECH-TM-435

AR-006-591

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Flight Mechanics Technical Memorandum 435

STAGNATION AND DYNAMIC PRESSURE LIMITS FOR THE S1 WIND TUNNEL

by

DAVID A. PIERENS

Approved for public release

SEPTEMBER 1991

AR-006-591

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
AERONAUTICAL RESEARCH LABORATORY

Flight Mechanics Technical Memorandum 435

STAGNATION AND DYNAMIC PRESSURE LIMITS FOR THE S1 WIND TUNNEL

by

David A. Pierens

SUMMARY

The information presented in this report outlines the absolute maximum pressures and the recommended maximum operating pressures for the S1 wind tunnel. The pressure limits calculated in this report were obtained from actual wind tunnel data records.

DSTO ARL SALISBURY

POSTAL ADDRESS: **Director, Aeronautical Research Laboratory**
506 Lorimer Street, Fishermens Bend 3207
Victoria Australia

CONTENTS

TABLES

FIGURES

NOTATION

A	Amps
c	speed of sound (m/s)
Const	a constant (y-intercept)
l	length
M	Mach number
p	static pressure (in.Hg or Pa)
P	dynamic pressure (in.Hg)
P_o	stagnation pressure (in.Hg)
$P_{o_{max}}$	maximum stagnation pressure (in.Hg)
R	gas constant
Re	Reynolds number
T	static temperature (K)
T_o	stagnation temperature (K)
v	velocity (ms^{-1})
γ	ratio of specific heats (= 1.4 for air)
μ	dynamic viscosity ($kgm^{-1}s^{-1}$)
ρ	density (kgm^{-3})

1. INTRODUCTION

Although the S1 wind tunnel has been in operation for many years, no attempt has been made to experimentally investigate and establish the operational pressure limits. Thus, it is not uncommon for new experimenters to request running conditions which the tunnel cannot achieve. This is further complicated by new temperature and current limits being adopted in 1985 after a main motor failure. Therefore a series of wind tunnel test runs were carried out in order to provide a reliable guide, outlining the running conditions which the S1 wind tunnel can safely achieve.

2. S1 WIND TUNNEL

The ARL-Salisbury S1 wind tunnel is a closed circuit, continuous, variable pressure wind tunnel, with a Mach number range of 0.35 to 1.0 and 1.4 to 2.8. The nominal dimensions of the tunnel's working section are 380 mm x 380 mm. To alleviate transonic blockage effects the upper and lower walls are longitudinally slotted. A schematic layout of the S1 wind tunnel is given in figure 1.

Mach number and dynamic pressure are derived from measurements of the static pressure on the wall of the working section and the total pressure from a pitot tube in the stagnation chamber near the entrance to the contraction. These values are taken to be the static and total pressures respectively of the working section flow.

3. METHOD

After the main motor failure of 1985 the safe operating limits of the S1 wind tunnel were defined as follows:

Max stator current:	310 Amps
Max rotor current:	1350 Amps
Max stator winding temp:	85° C
Max electrolyte temp:	65° C
Max stagnation temp:	65° C
Max stagnation pressure:	45 in. Hg (1.5 bar)

To determine how these limits related to the tunnel operating pressures, tests were run at the following test conditions, with the tunnel empty (ie. no model was present during testing).

Mach No.'s : 0.35, 0.5, 0.7, 0.9, 1.0, 1.4, 1.6, 1.8, 2.0, 2.2, 2.4, 2.8

Motor speed : 700 RPM, 800 RPM, 900 RPM, 1000 RPM

At a particular motor speed, the S1 wind tunnel was run at fixed Mach numbers while the stagnation pressure, P_o, was gradually increased. While increasing pressure and recording data, various parameters were continually observed as they approached their designated operating limits. It was noted that the stator or rotor current reached their operating limit before the other parameters.

From data collected at each test condition, graphs of stagnation pressure vs stator and rotor currents were produced. A linear fit was approximated for each graph, with equation (1) below, being used to calculate the maximum stagnation pressures corresponding to the stator and rotor current limits at each test condition.

$$P_O = \text{Const} + \frac{\delta P_o}{\delta A} * 310 \qquad \text{(when using stator amps)} \qquad (1a)$$

$$P_O = \text{Const} + \frac{\delta P_o}{\delta A} * 1350 \qquad \text{(when using rotor amps)} \qquad (1b)$$

The recorded wind tunnel data and calculation of maximum stagnation pressures are given in Appendix 1.

For each test condition, the lowest calculated pressure from equations 1a and 1b, was used as the absolute maximum stagnation pressure, $P_{o_{max}}$, at that Mach number and motor speed.

For motor speeds of 700, 800 and 900 RPM the absolute maximum stagnation pressure was dependent on the rotor current (ie. equation 1a). However, at 1000 RPM (synchronous speed), the rotor windings have been shorted out, resulting in the three electrolyte tanks (external resistance) and the rotor current meter (connected to one of the electrolyte tanks) being removed from the circuit. Consequently, no rotor current is monitored, although there is a considerable current passing through the rotor. Therefore, the stator current limit is used to calculate the absolute maximum stagnation pressure at 1000 RPM.

The pressure ratio $\frac{p}{P_{o_{max}}}$, $\left(\frac{\text{static}}{\text{stagnation}}\right)$, was calculated from the Mach number using equation (2).

$$\frac{p}{P_{o_{max}}} = \left(1 + \frac{\gamma-1}{2} M^2\right)^{\left(\frac{-\gamma}{\gamma-1}\right)} \qquad (2)$$

The dynamic pressure was calculated from equation (3).

$$P = \frac{\gamma}{2} p \, M^2 \qquad (3)$$

Using equations (1), (2) and (3), maximum pressure values were calculated at known Mach numbers, and curves of best fit approximated for absolute maximum stagnation and dynamic pressure Vs Mach number at the various motor speeds. The resulting curves are shown in figure 2. Recommended maximum operating pressures were taken to be 85% of the absolute maximum pressures to allow a suitable operational safety margin. Graphs showing the recommended maximum pressures are shown in figure 3. Tabulated values of absolute and recommended pressures are shown in tables 1 - 4.

Reynolds numbers for the S1 wind tunnel were obtained from equation (4).

$$Re = \frac{\rho v l}{\mu} \qquad (4)$$

The reference length was taken to be 1 metre, and hence the value of Reynolds number is given in the units, per metre.

Using the equation of state for a perfect gas shown below, the density at a particular pressure and temperature can be found.

$$\rho = \frac{p}{RT} \tag{5}$$

(For air at standard conditions R = 287 J/(kg.K).)

The viscosity of air under particular atmospheric conditions may be calculated from the equation below,

$$\frac{\mu_2}{\mu_1} = \left[\frac{T_2}{T_1}\right]^{\frac{3}{4}} \tag{6}$$

where μ_1 and μ_2 are the coefficients of dynamic viscosity at absolute temperatures T_1 and T_2 respectively. This formula is a good approximation over the range of pressures and temperatures usually met in aerodynamics.

At 0°C, 273.16 K, the value of μ for air is 1.714×10^{-5} $kgm^{-1}s^{-1}$. Therefore,

$$\mu = 1.714 \times 10^{-5} \left[\frac{T}{273.16}\right]^{\frac{3}{4}} \tag{7}$$

The tunnel velocity is calculated from the Mach number and the speed of sound, where the speed of sound is defined as,

$$c = \sqrt{\gamma RT} \tag{8}$$

Therefore, the tunnel velocity is given by equation (9).

$$v = M\sqrt{\gamma RT} \tag{9}$$

From known values of Mach number, static pressure and static temperature, corresponding values of Reynolds number can be obtained.

Static pressure was calculated from the pressure ratio equation stated in equation (2).

Static temperature was calculated from the following temperature ratio equation.

$$T = \frac{T_o}{(1 + \frac{\gamma-1}{2} * M^2)} \tag{10}$$

The normal stagnation temperature range encountered in the S1 wind tunnel is from 35°C to 55°C. It should be noted that stagnation temperatures above 50°C are approaching the absolute limits of the S1 wind tunnel. A stagnation temperature of 45°C is assumed to be an average temperature for testing, and was used in calculating obtainable Reynolds numbers.

Maximum obtainable Reynolds numbers were obtained using equations 4 - 11, together with the tested Mach numbers and corresponding maximum stagnation pressures (calculated earlier) and a stagnation temperature of 45°C. Curves of best fit were approximated for absolute maximum Reynolds number Vs Mach number at various motor speeds with the resulting curves shown in figure 4a. As with the recommended stagnation pressures, recommended maximum Reynolds numbers are taken to be 85% of the maximum obtainable Reynolds numbers, to allow a suitable operational safety margin (Refer to figure 4b). Tabulated values of absolute and recommended maximum Reynolds numbers are shown in tables 5 and 6.

To determine the effect on the pressure limits of the inclusion of a model, some tests from the previous experimental program were repeated, first with the working section empty and then with a typical missile model of 1.35% solid blockage mounted in the working section. Since the model was designed for subsonic conditions, only subsonic Mach numbers were used.

The conditions used in these tests were as follows.

Mach No.'s : 0.5, 0.7, 0.9

Motor speed : 700 RPM, 800 RPM, 900 RPM

Model pitch angles : 0°, 8°

The same stagnation and static pressures, as used in the previous test runs , were also used during the repeated tests where possible, and new stator and rotor currents recorded. Recorded data are shown in Appendix 2.

4. RESULTS AND DISCUSSION

The operational envelope of the S1 wind tunnel is outlined in the graphs in figures 2 - 4, and the accompanying tables 1 - 6. From these results it can been seen that the slower the motor speed, the higher the achievable stagnation pressure at a given Mach number. In the supersonic region the lower motor speeds become progressively unusable as the Mach number increases. This is because the lower motor speeds are unable to produce the pressure ratios needed for high supersonic speeds, resulting in a mixed supersonic/subsonic flow in the working section. In particular, it is recommended that 700 RPM not be used for any supersonic testing.

The results of the tests to determine the effect of a typical model in the working section indicated that the presence of the model had little effect on the maximum pressures obtainable. With the model present the effect on the motor currents varied from a 3% increase to a 2% decrease, generally within the range of experimental repeatability. An interesting additional finding , however, was that ambient weather conditions appear to have a greater effect, with test runs in winter conditions producing motor currents from 2% to 5% greater than in summer.

It has been found that the operating limits of the S1 wind tunnel are not dependent upon a single governing factor, but a contribution of many factors. In general, the stator and rotor currents are the major determinants of the wind tunnel's limits, but weather conditions appear to influence the relationship between maximum pressures and motor currents.. On a warm day, with an ambient air temperature of 30°C, the maximum pressures obtainable are higher than those on a cooler day, where the load on the tunnel is greater.

Other factors that restrict the performance of the S1 wind tunnel are stated below.

(i) Prolonged running of the wind tunnel will result in the stator and rotor winding temperatures rising.

(ii) When the S1 wind tunnel is operated close to the upper limit (ie. maximum stator and rotor current) of the main motor, the length of run is determined by the cooling of the plant, which changes from day to day depending on the weather conditions.

(iii) Low motor speed and a hot humid day will result in the electrolyte and tunnel air temperatures increasing. [Electrolyte and tunnel air are

cooled by water, with the efficiency of the cooling tower dependant on humidity and ambient temperature.]

It must be noted that the graphs (and corresponding tables) of absolute maximum stagnation pressure and dynamic pressure Vs Mach number (figure 2 and tables 1 and 2) are based upon results obtained on a typical summer day, and consequently the maximum attainable pressures may be somewhat lower when testing is carried out on cooler days. However, the recommended pressure limits of the S1 wind tunnel, which are defined as 85% of the maximum attainable pressures, should cover all running conditions including changes in the ambient air temperature.

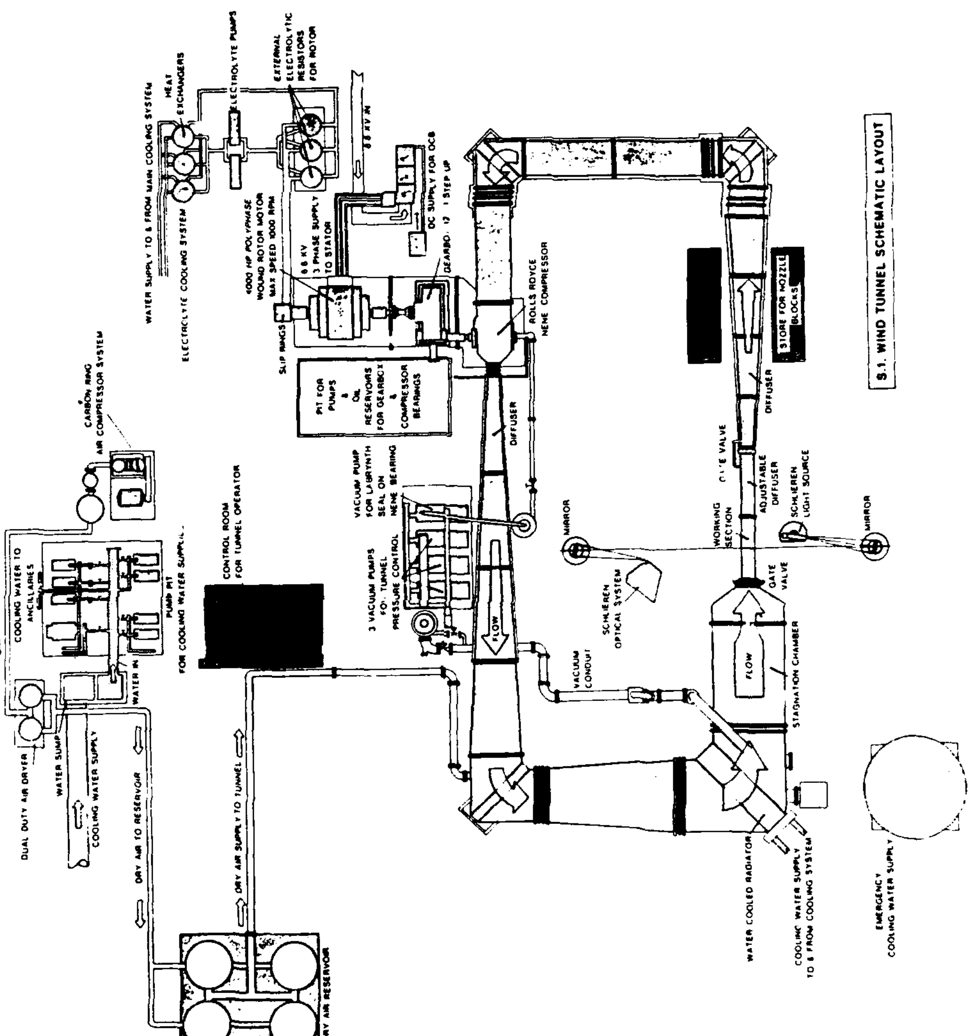
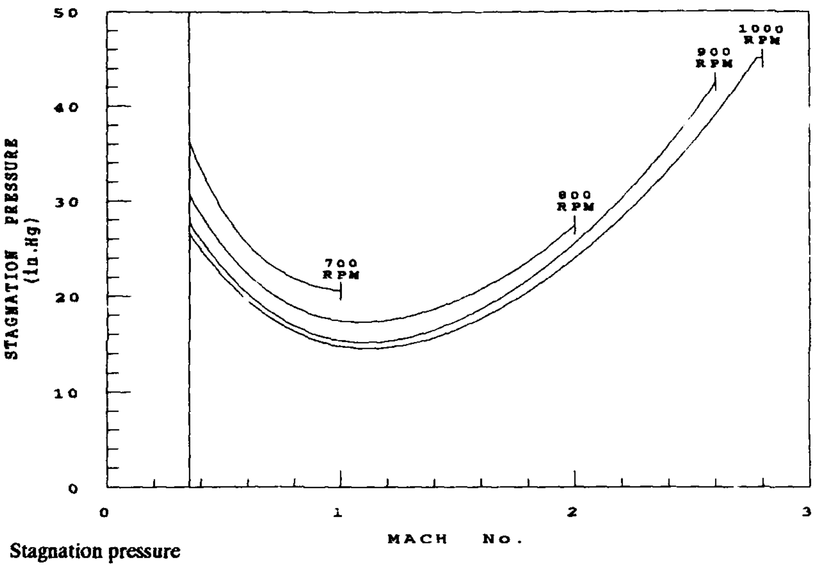
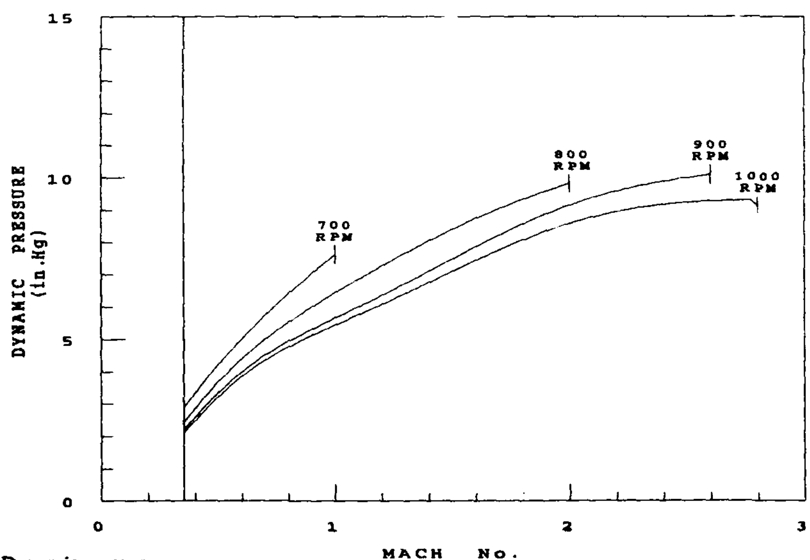


Figure 1. ARL - Salisbury S1 wind tunnel schematic layout



(a) Stagnation pressure



(b) Dynamic pressure

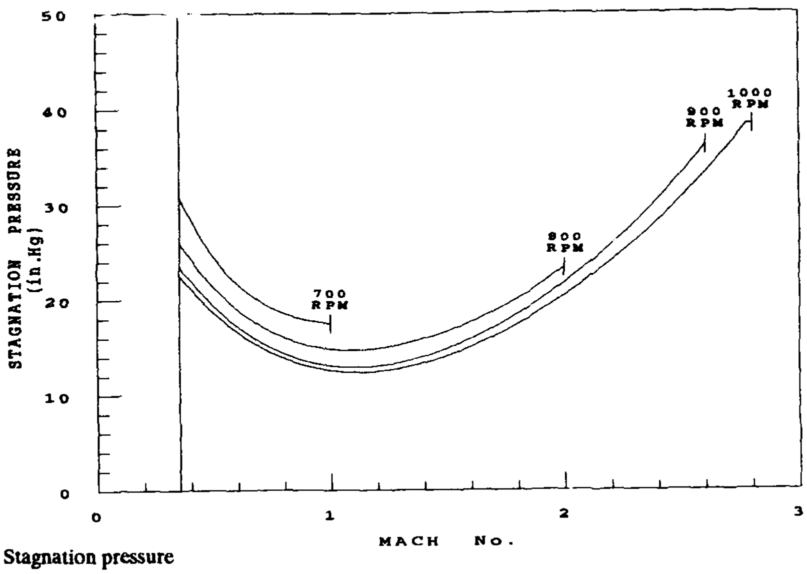
Figure 2. Absolute maximum pressure limits

Table 1. Absolute maximum stagnation pressure limits

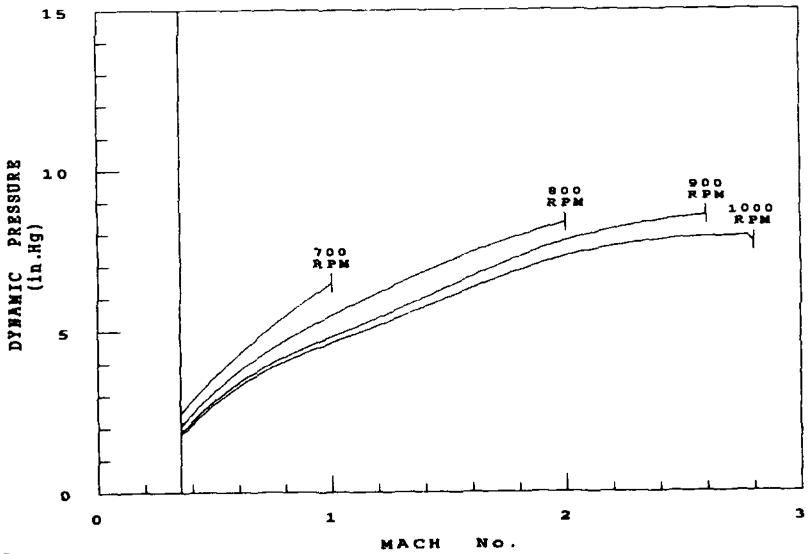
	STAGNATION PRESSURE (in.Hg)			
Mach No.	**700 RPM**	**800 RPM**	**900 RPM**	**1000 RPM**
0.35	36.29	30.63	27.71	26.56
0.40	33.35	28.55	25.88	24.85
0.50	28.72	25.04	22.75	21.90
0.60	25.46	22.32	20.24	23.25
0.70	2[illegible].25	20.29	18.30	17.66
0.80	21.8[illegible]	18.85	16.87	16.28
0.90	21.02	17.92	15.90	15.33
1.00	20.60	17.42	15.34	14.76
1.40	-	18.66	16.48	15.67
1.60	-	20.72	18.65	17.64
1.80	-	23.61	21.69	20.43
2.00	-	27.42	25.54	23.96
2.20	-	-	30.22	28.21
2.40	-	-	35.81	33.22
2.60	-	-	42.49	39.09
2.80	-	-	-	45.00

Table 2. Absolute maximum dynamic pressure limits

	DYNAMIC PRESSURE (in.Hg)			
Mach No.	**700 RPM**	**800 RPM**	**900 RPM**	**1000 RPM**
0.35	2.86	2.41	2.18	2.09
0.40	3.35	2.86	2.60	2.49
0.50	4.24	3.69	3.36	3.23
0.60	5.03	4.41	4.00	3.86
0.70	5.75	5.02	4.52	4.37
0.80	6.42	5.54	4.96	4.78
0.90	7.05	6.01	5.33	5.14
1.00	7.62	6.44	5.67	5.46
1.40	-	8.05	7.10	6.76
1.60	-	8.74	7.86	7.44
1.80	-	9.32	8.56	8.07
2.00	-	9.81	9.14	8.57
2.20	-	-	9.57	8.94
2.40	-	-	9.88	9.16
2.60	-	-	10.08	9.27
2.80	-	-	-	9.10



(a) Stagnation pressure



(b) Dynamic pressure

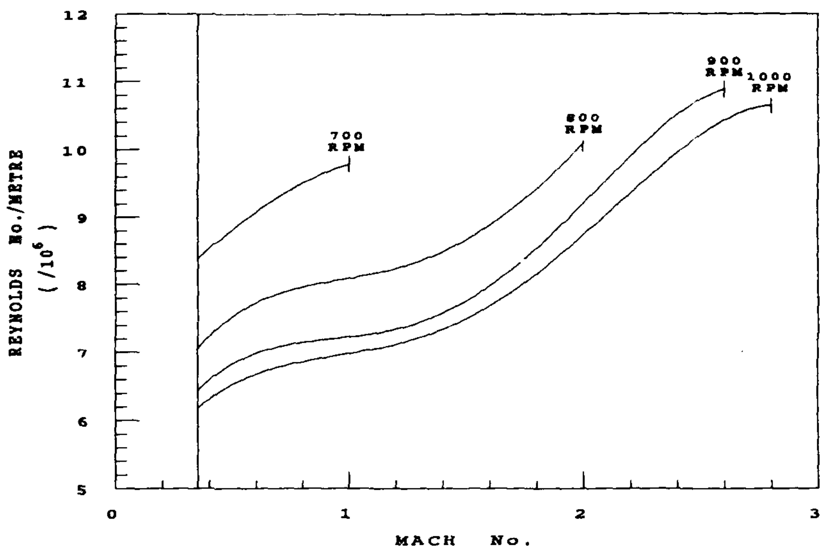
Figure 3. Recommended maximum pressure limits

Table 3. Recommended maximum stagnation pressure limits

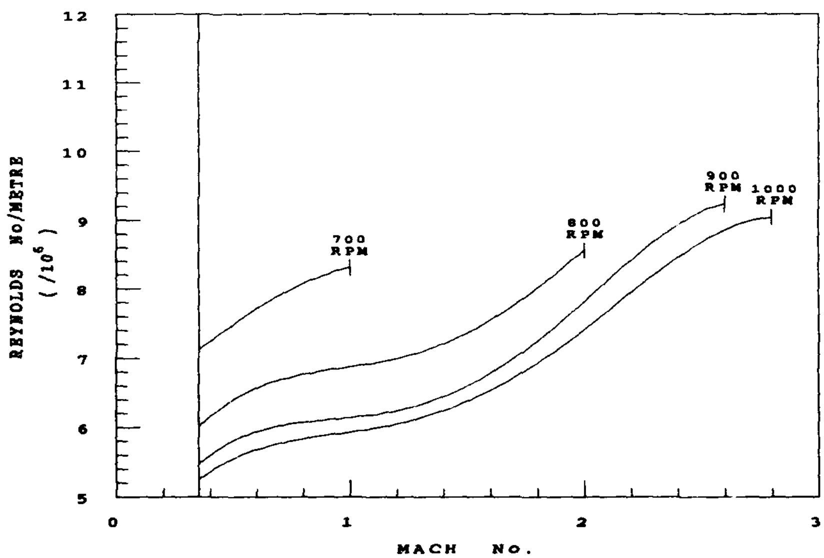
Mach No.	STAGNATION PRESSURE (in.Hg) 700 RPM	800 RPM	900 RPM	1000 RPM
0.35	30.84	26.04	23.55	22.58
0.40	28.35	24.26	22.00	21.12
0.50	24.42	21.28	19.33	18.61
0.60	21.64	18.97	17.20	16.59
0.70	19.76	17.25	15.55	15.01
0.80	18.56	16.02	14.34	13.84
0.90	17.86	15.23	13.51	13.03
1.00	17.51	14.81	13.04	12.55
1.40	-	15.85	14.00	13.32
1.60	-	17.61	15.85	15.00
1.80	-	20.07	18.44	17.37
2.00	-	23.31	21.71	20.37
2.20	-	-	25.69	23.98
2.40	-	-	30.44	28.23
2.60	-	-	36.12	33.23
2.80	-	-	-	38.25

Table 4. Recommended maximum dynamic pressure limits

Mach No.	DYNAMIC PRESSURE (in.Hg) 700 RPM	800 RPM	900 RPM	1000 RPM
0.35	2.43	2.05	1.86	1.78
0.40	2.84	2.43	2.21	2.12
0.50	3.60	3.14	2.85	2.75
0.60	4.28	3.75	3.40	3.28
0.70	4.89	4.26	3.85	3.71
0.80	5.46	4.71	4.21	4.07
0.90	5.99	5.11	4.53	4.37
1.00	6.48	5.48	4.82	4.64
1.40	-	6.84	6.04	5.74
1.60	-	7.43	6.68	6.32
1.80	-	7.92	7.28	6.86
2.00	-	8.34	7.77	7.29
2.20	-	-	8.14	7.60
2.40	-	-	8.40	7.79
2.60	-	-	8.57	7.88
2.80	-	-	-	7.74



(a) Maximum obtainable Reynolds numbers



(b) Recommended maximum Reynolds numbers

Figure 4. Obtainable Reynolds numbers

Table 5. Maximum obtainable Reynolds numbers

Mach No.	REYNOLDS No. / METRE ($/10^6$) 700 RPM	800 RPM	900 RPM	1000 RPM
0.35	8.38	7.06	6.43	6.17
0.40	8.53	7.24	6.59	6.31
0.50	8.81	7.53	6.83	6.53
0.60	9.08	7.73	6.99	6.68
0.70	9.31	7.87	7.09	6.79
0.80	9.51	7.96	7.15	6.86
0.90	9.66	8.03	7.19	6.92
1.00	9.78	8.09	7.23	6.98
1.40	-	8.48	7.58	7.34
1.60	-	8.88	7.98	7.69
1.80	-	9.42	8.53	8.15
2.00	-	10.09	9.20	8.73
2.20	-	-	9.90	9.35
2.40	-	-	10.51	9.95
2.60	-	-	10.88	10.43
2.80	-	-	-	10.64

Table 6. Recommended maximum obtainable Reynolds numbers

Mach No.	REYNOLDS No. / METRE ($/10^6$) 700 RPM	800 RPM	900 RPM	1000 RPM
0.35	7.12	6.00	5.47	5.25
0.40	7.25	6.16	5.60	5.36
0.50	7.49	6.40	5.81	5.55
0.60	7.72	6.57	5.94	5.68
0.70	7.91	6.69	6.02	5.77
0.80	8.08	6.77	6.07	5.83
0.90	8.21	6.83	6.11	5.89
1.00	8.31	6.88	6.14	5.93
1.40	-	7.21	6.45	6.24
1.60	-	7.55	6.78	6.53
1.80	-	8.01	7.25	6.93
2.00	-	8.57	7.82	7.42
2.20	-	-	8.41	7.95
2.40	-	-	8.93	8.46
2.60	-	-	9.24	8.86
2.80	-	-	-	9.05

APPENDIX 1 Calculation of Pressure Limits
(all pressures are given in inches Hg.)

MOTOR SPEED = 700 RPM

		RECORDED DATA			CALCULATION OF PRESSURE LIMITS			
MACH No.	STAG. PRESS.	STATIC PRESS.	STATOR AMPS	ROTOR AMPS	STATOR Const	STATOR $\frac{\delta P_o}{\delta A}$	ROTOR Const	ROTOR $\frac{\delta P_o}{\delta A}$
0.35	21.42	19.55	182	800	-3.58	0.138	-0.16	0.027
	28.56	26.07	230	1040				
	35.70	32.62	285	1325	Max P_o = 39.30		Max P_o = 36.61	
	36.80	33.63	292	1355	(at 310 amps)		(at 1350 amps)	
0.50	27.24	22.96	275	1290	-0.62	0.101	-2.55	0.023
	27.70	23.37	280	1300				
	28.95	24.44	292	1360	Max P_o = 30.76		Max P_o 28.74	
					(at 310 amps)		(at 1350 amps)	
0.70	22.02	15.87	272	1260	0.51	0.078	-1.10	0.018
	22.20	16.38	282	1300				
	23.77	17.14	295	1360	Max P_o = 24.78		Max P_o = 23.45	
					(at 310 amps)		(at 1350 amps)	
0.90	19.75	11.68	265	1220	-2.08	0.082	-0.37	0.017
	21.20	12.57	282	1300				
	22.05	13.08	293	1360	Max P_o = 23.47		Max P_o = 21.94	
					(at 310 amps)		(at 1350 amps)	
1.00	19.27	10.18	262	1210	-1.83	0.080	-0.52	0.016
	20.80	10.95	282	1300				
	21.55	11.38	290	1350	Max P_o = 23.12		Max P_o = 21.58	
					(at 310 amps)		(at 1350 amps)	
1.40	13.20	5.07	188	830	-2.41	0.084	-0.19	0.016
	15.98	6.15	218	980				
	18.22	7.02	246	1140	Max P_o = 23.52		Max P_o = 21.77	
	20.08	7.73	270	1245	(at 310 amps)		(at 1350 amps)	
1.60	15.49	4.23	194	865	0.25	0.079	1.82	0.016
	17.58	4.80	218	980				
	19.82	5.42	240	110	Max P_o = 24.86		Max P_o = 23.41	
	20.35	5.82	258	1180	(at 310 amps)		(at 1350 amps)	
1.80	15.83	3.47	178	790	-1.97	0.101	0.39	0.020
	18.89	4.14	206	930				
	21.21	4.65	230	1050	Max P_o = 29.25		Max P_o = 27.07	
	24.98	5.49	265	1230	(at 310 amps)		(at 1350 amps)	
	26.18	5.74	282	1320				

MOTOR SPEED = 700 RPM

RECORDED DATA

CALCULATION OF PRESSURE LIMITS

MACH No.	STAG. PRESS.	STATIC PRESS.	STATOR AMPS	ROTOR AMPS	STATOR Const	STATOR $\frac{\delta P_o}{\delta A}$	ROTOR Const	ROTOR $\frac{\delta P_o}{\delta A}$
2.00	20.57	2.74	190	850	-2.46	0.121	0.67	0.023
	24.00	3.20	220	998				
	27.35	3.63	246	1140	Max P_o = 35.02		Max P_o = 32.25	
					(at 310 amps)		(at 1350 amps)	

For Mach numbers 1.4 and higher it was noticed that the flow progressively breaks up into a mixed supersonic/subsonic flow as the stagnation pressure increases. It is therefore recommended not to run the tunnel at this motor speed for Mach numbers of 1.4 and higher, as the model could be damaged.

MOTOR SPEED = 800 RPM

	RECORDED DATA				CALCULATION OF PRESSURE LIMITS			
MACH No.	**STAG. PRESS.**	**STATIC PRESS.**	**STATOR AMPS**	**ROTOR AMPS**	**STATOR Const**	**STATOR** $\frac{\delta P_o}{\delta A}$	**ROTOR Const**	**ROTOR** $\frac{\delta P_o}{\delta A}$
0.35	28.56	26.24	262	1240	1.39	0.104	1.49	0.022
	30.20	27.56	278	1300				
	30.95	28.25	285	1350	Max P_o = 33.53		Max P_o = 31.07	
					(at 310 amps)		(at 1350 amps)	
0.50	20.00	16.86	236	1100	-0.65	0.088	0.75	0.018
	22.30	18.78	262	1230				
	24.20	20.40	284	1340	Max P_o = 26.48		Max P_o = 24.38	
					(at 310 amps)		(at 1350 amps)	
0.70	18.20	13.13	262	1240	0.57	0.067	-0.10	0.015
	19.45	13.98	280	1320				
	19.80	14.25	286	1350	Max P_o = 21.44		Max P_o = 19.84	
					(at 310 amps)		(at 1350 amps)	
0.90	16.43	9.69	258	1210	-1.20	0.068	-0.11	0.014
	17.85	10.52	280	1320				
	18.38	10.83	286	1350	Max P_o = 19.97		Max P_o = 18.33	
					(at 310 amps)		(at 1350 amps)	
1.00	15.45	8.16	245	1150	-0.15	0.064	0.79	0.013
	16.85	8.90	268	1260				
	18.00	9.50	285	1350	Max P_o = 19.56		Max P_o = 18.00	
					(at 310 amps)		(at 1350 amps)	
1.40	11.91	4.57	194	875	-1.44	0.069	0.02	0.014
	14.54	5.59	230	1060				
	16.51	6.36	260	1220	Max P_o = 19.97		Max P_o =18.41	
	17.52	6.74	275	1280	(at 310 amps)		(at 1350 amps)	
1.60	13.48	3.67	198	890	-2.60	0.082	0.01	0.015
	15.00	4.09	215	980				
	17.31	4.72	242	1140	Max P_o = 22.71		Max P_o =20.53	
	19.01	5.19	266	1250	(at 310 amps)		(at 1350 amps)	
1.80	12.86	2.81	170	760	-2.64	0.091	-0.71	0.018
	15.21	3.37	195	900				
	17.38	3.81	218	1010	Max P_o = 25.72		Max P_o =23.33	
	20.24	4.44	250	1180	(at 310 amps)		(at 1350 amps)	
	22.47	4.93	275	1300				
2.00	16.55	2.22	180	810	-2.74	0.107	0.10	0.020
	19.75	2.64	210	960				
	24.05	3.21	248	1170	Max P_o = 30.52		Max P_o =27.63	
	26.32	3.51	272	1290	(at 310 amps)		(at 1350 amps)	

MOTOR SPEED = 800 RPM

RECORDED DATA					CALCULATION OF PRESSURE LIMITS			
MACH No.	**STAG. PRESS.**	**STATIC PRESS.**	**STATOR AMPS**	**ROTOR AMPS**	**STATOR Const**	**STATOR $\frac{\delta P_o}{\delta A}$**	**ROTOR Const**	**ROTOR $\frac{\delta P_o}{\delta A}$**
2.20	20.15	2.05	185	845	-3.40	0.127	-1.03	0.025
	23.01	2.35	208	950				
	25.65	2.61	228	1050	Max P_o = 36.03		Max P_o =33.05	
	29.85	3.02	262	1220	(at 310 amps)		(at 1350 amps)	
	31.63	3.20	275	1300				
2.40	16.45	1.15	142	580	-5.17	0.155	-0.76	0.029
	21.05	1.50	168	750				
	26.08	1.84	200	910	Max P_o = 42.79		Max P_o =38.96	
	30.79	2.18	232	1070	(at 310 amps)		(at 1350 amps)	
	35.12	2.49	262	1220				

For a Mach no. of 2.20 it was noted that the flow progressively breaks up into a mixed supersonic/subsonic flow. It is advisable not to run at this motor speed for Mach numbers of 2.20 and higher.

MOTOR SPEED = 900 RPM

		RECORDED DATA			CALCULATION OF PRESSURE LIMITS			
MACH No.	STAG. PRESS.	STATIC PRESS.	STATOR AMPS	ROTOR AMPS	STATOR Const	STATOR $\frac{\delta P_o}{\delta A}$	ROTOR Const	ROTOR $\frac{\delta P_o}{\delta A}$
0.35	23.00	20.95	240	1125	-1.81	0.103	-3.01	0.023
	25.00	22.78	262	1200				
	26.70	24.35	278	1280	Max P_o = 30.10		Max P_o = 28.32	
	27.80	25.35	286	1330	(at 310 amps)		(at 1350 amps)	
0.50	20.00	16.86	268	1240	-4.42	0.091	-2.62	0.018
	21.30	17.95	282	1300				
	22.00	18.55	290	1350	Max P_o = 23.83		Max P_o = 22.08	
					(at 310 amps)		(at 1350 amps)	
0.70	16.40	11.84	272	1260	-3.74	0.074	-2.61	0.015
	16.92	12.18	278	1300				
	17.75	12.79	290	1350	Max P_o = 19.25		Max P_o = 17.73	
					(at 310 amps)		(at 1350 amps)	
0.90	14.50	8.57	260	1210	-0.92	0.059	-1.66	0.013
	15.53	9.18	278	1300				
	16.40	9.68	292	1350	Max P_o = 17.45		Max P_o = 16.32	
					(at 310 amps)		(at 1350 amps)	
1.00	13.50	7.13	246	1155	-0.27	0.056	-1.74	0.013
	14.44	7.60	262	1220				
	15.47	8.15	280	1300	Max P_o = 17.11		Max P_o = 16.11	
	15.95	8.43	290	1340	(at 310 amps)		(at 1350 amps)	
1.40	9.10	3.48	175	795	-1.87	0.063	-1.39	0.013
	10.73	4.12	200	910				
	12.37	4.75	226	1040	Max P_o = 17.63		Max P_o = 16.50	
	14.52	5.58	260	1200	(at 310 amps)		(at 1350 amps)	
	15.82	6.08	282	1300				
1.60	11.43	3.12	192	880	-1.66	0.068	-1.25	0.014
	13.32	3.63	218	1000				
	15.08	4.12	244	1130	Max P_o = 19.55		Max P_o = 18.30	
	16.57	4.52	268	1225	(at 310 amps)		(at 1350 amps)	
	17.95	4.90	286	1330				
1.80	11.81	2.59	178	810	-1.83	0.077	-1.49	0.016
	13.79	3.02	202	940				
	16.11	3.53	232	1070	Max P_o = 22.06		Max P_o = 20.61	
	17.70	3.87	252	1170	(at 310 amps)		(at 1350 amps)	
	18.85	4.13	270	1245				

MOTOR SPEED = 900 RPM

	RECORDED DATA				**CALCULATION OF PRESSURE LIMITS**			
MACH No.	**STAG. PRESS.**	**STATIC PRESS.**	**STATOR AMPS**	**ROTOR AMPS**	**STATOR Const**	**STATOR $\frac{\delta P_o}{\delta A}$**	**ROTOR Const**	**ROTOR $\frac{\delta P_o}{\delta A}$**
2.00	14.42	1.94	178	805	-2.75	0.097	-1.97	0.020
	17.28	2.32	206	940				
	20.77	2.77	242	1120	Max P_o = 27.29		Max P_o = 25.56	
	23.62	3.15	272	1250	(at 310 amps)		(at 1350 amps)	
	24.50	3.27	282	1300				
2.20	19.00	1.95	195	890	-2.46	0.111	-2.08	0.024
	22.23	2.27	220	1010				
	24.48	2.50	242	1110	Max P_o = 31.97		Max P_o = 30.14	
	27.40	2.79	270	1240	(at 310 amps)		(at 1350 amps)	
2.40	22.57	1.60	196	900	-3.42	0.133	-2.62	0.028
	26.39	1.87	225	1025				
	30.45	2.16	253	1175	Max P_o = 37.75		Max P_o = 35.35	
	33.88	2.60	282	1300	(at 310 amps)		(at 1350 amps)	
2.60	13.35	0.73	122	500	-6.57	0.166	-3.22	0.033
	20.30	1.13	160	705				
	27.10	1.52	200	920	Max P_o = 45.00		Max P_o = 41.56	
	33.92	1.90	243	1120	(at 310 amps)		(at 1350 amps)	
	37.00	2.08	264	1210				

The tunnel cannot achieve Mach numbers greater than 2.60 at a motor speed of 900 RPM.

MOTOR SPEED = 1000 RPM

	RECORDED DATA				CALCULATION OF PRESSURE LIMITS			
MACH	STAG.	STATIC	STATOR	ROTOR	STATOR		ROTOR	
No.	PRESS.	PRESS.	AMPS	AMPS	Const	$\frac{\delta P_o}{\delta A}$	Const	$\frac{\delta P_o}{\delta A}$
0.35	23.15	21.10	265	-	-1.18	0.092	-	-
	24.55	22.40	280	-				
	25.50	23.30	290	-	Max P_o = 27.30			-
	26.35	24.03	300	-	(at 310 amps)			-
0.50	17.35	14.63	256	-	0.92	0.064	-	-
	18.44	15.53	272	-				
	19.60	16.50	290	-	Max P_o= 20.85			-
	20.30	17.12	302	-	(at 310 amps)			-
0.70	14.80	10.68	268	-	0.01	0.055	-	-
	15.57	11.23	282	-				
	16.25	11.71	295	-	Max P_o = 17.11			-
	16.75	12.06	303	-	(at 310 amps)			-
0.90	12.50	7.39	248	-	-0.57	0.053	-	-
	13.40	7.92	266	-				
	14.55	8.60	288	-	Max P_o = 15.74			-
	15.40	9.10	303	-	(at 310 amps)			-
1.00	12.50	6.60	252	-	-0.99	0.054	-	-
	13.95	7.30	278	-				
	14.85	7.80	296	-	Max P_o = 15.62			-
	15.25	8.00	303	-	(at 310 amps)			-
1.40	9.46	3.63	198	-	-1.57	0.056	-	-
	11.01	4.23	224	-				
	13.22	5.08	262	-	Max P_o = 15.80			-
	14.16	5.45	280	-	(at 310 amps)			-
	15.02	5.77	298	-				
1.60	10.76	2.93	200	-	-1.73	0.063	-	-
	12.20	3.33	220	-				
	13.59	3.70	242	-	Max P_o = 17.79			-
	14.75	4.02	262	-	(at 310 amps)			-
	15.97	4.36	282	-				
1.80	9.53	2.08	164	-	-1.71	0.069	-	-
	11.97	2.62	198	-				
	14.06	3.09	228	-	Max P_o = 19.65			-
	17.05	3.73	272	-	(at 310 amps)			-
	18.07	3.96	288	-				
2.00	15.30	2.06	210	-	-2.69	0.086	-	-
	17.44	2.35	232	-				
	19.90	2.67	262	-	Max P_o = 24.02			-
	21.55	2.88	282	-	(at 310 amps)			-

MOTOR SPEED = 1000 RPM

MACH No.	STAG. PRESS.	STATIC PRESS.	STATOR AMPS	ROTOR AMPS	STATOR Const	STATOR $\frac{\delta P_o}{\delta A}$	ROTOR Const	ROTOR $\frac{\delta P_o}{\delta A}$
	RECORDED DATA				CALCULATION OF PRESSURE LIMITS			
2.20	15.35	1.57	180	-	-3.14	0.103	-	-
	19.45	1.99	220	-				
	22.74	2.32	250	-	Max P_o = 28.75		-	
	25.08	2.56	275	-	(at 310 amps)		-	
	26.66	2.72	290	-				
2.40	20.91	1.48	200	-	-2.34	0.116	-	-
	23.41	1.65	222	-				
	27.00	1.91	252	-	Max P_o = 33.68		-	
	29.28	2.07	272	-	(at 310 amps)		-	
	31.56	2.24	292	-				
2.60	22.00	1.24	185	-	-3.57	0.139	-	-
	27.45	1.54	224	-				
	31.80	1.78	254	-	Max P_o = 39.37		-	
	35.78	2.01	285	-	(at 310 amps)		-	
2.80	26.95	1.08	192	-	-4.12	0.162	-	-
	31.60	1.27	220	-				
	35.00	1.40	240	-	Max P_o = 46.17		-	
	38.25	1.52	262	-	(at 310 amps)		-	
	40.00	1.60	272	-				

The tunnel cannot achieve Mach numbers greater than 2.80.

APPENDIX 2 Comparison of tunnel loading for tunnel empty and tunnel occupied
(Both runs conducted during winter)

Mach No.	RPM	Pitch Angle (deg)	Pressure (in.Hg) Stag.	Ref.	Stator (amps) Tunnel empty	Tunnel occupied	%	Rotor (amps) Tunnel empty	Tunnel occupied	%
0.5	700	0	27.24	22.96	286	288	0.7	1340	1340	0.0
		8	"	"	286	288	0.7	1340	1340	0.0
	800	0	22.30	18.78	270	270	0.0	1280	1260	-1.6
		8	"	"	270	270	0.0	1280	1260	-1.6
0.7	700	0	22.02	15.87	285	280	-1.8	1320	1295	-1.9
		8	"	"	285	280	-1.8	1320	1295	-1.9
	800	0	18.20	13.13	274	270	-1.5	1300	1270	-2.3
		8	"	"	274	270	-1.5	1300	1270	-2.3
	900	0	16.40	11.84	282	280	-0.7	1295	1298	0.2
		8	"	"	282	280	-0.7	1295	1298	0.2
		0	16.92	12.18	290	288	-0.7	1340	1325	-1.1
		8	"	"	290	288	-0.7	1340	1325	-1.1
0.9	700	0	19.75	11.68	278	280	0.7	1280	1300	1.5
		8	"	"	278	280	0.7	1280	1300	1.5
	800	0	16.43	9.69	268	272	1.5	1250	1270	1.6
		8	"	"	268	272	1.5	1250	1270	1.6
	900	0	14.50	8.57	270	272	0.7	1250	1260	0.8
		8	"	"	270	272	0.7	1250	1260	0.8
		0	15.53	9.18	288	288	0.0	1320	1340	1.5
		8	"	"	288	290	0.7	1320	1345	1.9

APPENDIX 3 **Comparison of tunnel loading for tunnel empty during Summer and Winter**

Mach No.	RPM	Pressure (in.Hg)		Stator (amps)			Rotor (amps)		
		Stag.	Ref.	Summer	Winter	%	Summer	Winter	%
0.5	700	27.24	22.96	275	286	4.0	1290	1340	3.9
	300	20.00	16.86	236	243	2.9	1100	1150	4.5
		22.30	18.78	262	270	3.1	1230	1280	4.1
	900	20.00	16.86	268	278	3.7	1240	1270	2.4
	1000	17.35	14.63	265	270	1.9	-	-	-
		18.44	15.53	280	285	1.8	-	-	-
0.7	700	22.02	15.87	272	285	4.8	1260	1320	4.8
	800	18.20	13.13	262	274	4.6	1240	1300	4.8
	900	16.40	11.84	272	282	3.7	1260	1295	2.8
		16.92	12.18	278	290	4.3	1300	1340	3.1
	1000	15.57	11.23	282	295	4.6	-	-	-
0.9	700	19.75	11.68	265	278	4.9	1220	1280	4.9
		21.20	12.57	282	292	3.5	1300	1350	3.8
	800	16.43	9.69	258	268	3.9	1210	1250	3.3
		17.85	10.52	280	288	2.9	1320	1350	2.3
								00	
	900	14.50	8.57	260	270	3.8	1210	1250	3.3
		15.53	9.18	278	288	3.7	1300	1320	1.5
	1000	12.50	7.39	248	258	4.0	-	-	-
		13.40	7.92	266	275	3.4	-	-	-

DISTRIBUTION

AUSTRALIA

Department of Defence

Defence Central

Chief Defence Scientist)
AS, Science Corporate Management)shared copy
FAS Science Policy)
Director, Departmental Publications
Counsellor, Defence Science, London (Doc Data Sheet Only)
Counsellor, Defence Science, Washington (Doc Data Sheet Only)
Scientific Adviser, Defence Central
OIC TRS, Defence Central Library
Document Exchange Centre, DSTIC (8 copies)
Defence Intelligence Organisation
Librarian H Block, Victoria Barracks, Melb (Doc Data Sheet Only)

Aeronautical Research Laboratory

Director
Library
Chief of Flight Mechanics and Propulsion Division
Branch Head - Flight Mechanics
Branch File - Flight Mechanics
Author: D.A. Pierens
POWA Group
POASI Group
G. Gordon, WA Group
WA/ASI Library

Defence Science & Technology Organisation - Salisbury

Library
Chief, Guided Weapon Division, WSRL

Navy Office

Navy Scientific Adviser (3 Copies Doc Data Sheet)

Army Office

Scientific Adviser - Army (Doc Data Sheet Only)

Air Force Office

Air Force Scientific Adviser (Doc Data Sheet Oniy)

SPARES (8 COPIES)

TOTAL (33 COPIES)

AL 149 DEPARTMENT OF DEFENCE

DOCUMENT CONTROL DATA

PAGE CLASSIFICATION
UNCLASSIFIED

PRIVACY MARKING

1a. AR NUMBER AR-006-591	1b. ESTABLISHMENT NUMBER ARL-FLIGHT MECH-TM-435	2. DOCUMENT DATE SEPTEMBER 1991	3. TASK NUMBER DST 91/072

4. TITLE
STAGNATION AND DYNAMIC PRESSURE LIMITS FOR THE S1 WIND TUNNEL

5. SECURITY CLASSIFICATION
(PLACE APPROPRIATE CLASSIFICATION IN BOX(S) IE. SECRET (S), CONF. (C) RESTRICTED (R), UNCLASSIFIED (U)).

U	U	U
DOCUMENT	TITLE	ABSTRACT

6. NO. PAGES
25

7. NO. REFS.
-

8. AUTHOR(S)
DAVID A. PIERENS

9. DOWNGRADING/DELIMITING INSTRUCTIONS
Not applicable

10. CORPORATE AUTHOR AND ADDRESS
AERONAUTICAL RESEARCH LABORATORY
506 LORIMER STREET
FISHERMENS BEND VIC 3207

11. OFFICE/POSITION RESPONSIBLE FOR:
SPONSOR DSTO
SECURITY -
DOWNGRADING -
APPROVAL CFPD

12. SECONDARY DISTRIBUTION (OF THIS DOCUMENT)
Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DSTIC, ADMINISTRATIVE SERVICES BRANCH, DEPARTMENT OF DEFENCE, ANZAC PARK WEST OFFICES, ACT 2601

13a. THIS DOCUMENT MAY BE ANNOUNCED IN CATALOGUES AND AWARENESS SERVICES AVAILABLE TO . . . .
No limitations

13b. CITATION FOR OTHER PURPOSES (IE. CASUAL ANNOUNCEMENT) MAY BE [X] UNRESTRICTED OR [ ] AS FOR 13a.

14. DESCRIPTORS
Transonic wind tunnels
Dynamic stagnation
Dynamic pressure
Performance tests

15. DISCAT SUBJECT CATEGORIES
010101
2004

16. ABSTRACT

The information contained in this report outlines the absolute maximum pressures and the recommended operating pressures for the S1 wind tunnel. The pressure limits calculated in this report were obtained from actual wind tunnel data records.

PAGE CLASSIFICATION
UNCLASSIFIED
PRIVACY MARKING

THIS PAGE IS TO BE USED TO RECORD INFORMATION WHICH IS REQUIRED BY THE ESTABLISHMENT FOR ITS OWN USE BUT WHICH WILL NOT BE ADDED TO THE DISTIS DATA UNLESS SPECIFICALLY REQUESTED.

16. ABSTRACT (CONT).

17. IMPRINT

AERONAUTICAL RESEARCH LABORATORY, MELBOURNE

18. DOCUMENT SERIES AND NUMBER	19. COST CODE	20. TYPE OF REPORT AND PERIOD COVERED
Flight Mechanics Technical Memorandum 435	58 591A	

21. COMPUTER PROGRAMS USED

22. ESTABLISHMENT FILE REF.(S)

23. ADDITIONAL INFORMATION (AS REQUIRED)